Resolving magnetic and chemical correlation lengths in CoPtCr-based recording media

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GRANULAR RECORDING MEDIA

Current magnetic recording media consists of chemically segregated, polycrystalline grains whose grain-centers are ferromagnetic with in-plane anisotropy and whose grain boundaries are nominally non-magnetic [1]. This chemically and magnetically heterogeneous microstructure has evolved through several generations of recording media via an increasingly complex set of alloys from CoCr to CoPtCr to CoPtCrB. The additives Cr and later B are known to segregate to and produce nonmagnetic grain boundary phases that were believed to reduce exchange coupling between adjacent grains, thereby enabling sharper bit transitions and higher recording density [2]. Chemical heterogeneity associated with these films is resolved using high-resolution TEM and micro-EELS [3]. It has remained difficult, however, to directly measure the magnetic correlation lengths giving the distance over which grain-to-grain magnetism is correlated.

We have found that both magnetic and chemical heterogeneity in recording media films are strong scattering sources when tuned to specific soft x-ray core resonances to enhance contrast [4,5]. This transmission small-angle scattering (SAS) measurement positions the scattering vector q in the film plane to optimize coupling to in-plane structure (Fig. 1b, inset) [6]. Although soft x-ray wavelengths limit the maximum q, spatial resolution to 1 nm is available.

Q-RESOLVED RESONANT SCATTERING

SAS q scans measured at the resonant intensity peaks at the Co and Cr L_3 lines are shown in Fig. 1. Scans of the common underlayer structure (without any media layer) reveal the contributions from the underlayer and the SiN membrane. These scans are almost featureless, with enhanced low q scattering that is also observed in scattering from the substrate alone, and with a weak, broad peak at $q \cong 0.015$ Å^{-1} observed at the Cr resonance. For the samples with media layers there is additional, strong SAS at both the Cr and Co edges arising from the media layer. This scattering is strongly resonantly enhanced, as is illustrated in Fig. 1b by the 10-fold decrease in scattering just 10 eV below the Co L_3 peak (dashed line) compared to that measured at the peak (open circles). Similarly strong and sharp resonant enhancements are observed near the Cr L_3 line.

The SAS scans from the different media samples show similar features. The Cr-edge data has a peak at $q \cong 0.07$ Å^{-1} for all samples. This peak results from interference between neighboring scattering centers separated by $2\pi/q \cong 100$ Å, typical of grain diameters observed in TEM images of media grown on similar underlayers [2]. We attribute this Cr resonant peak to the average grain diameter of the media. It is well established that chemical segregation during the growth of CoCr alloys involves Cr diffusion to the grain boundaries resulting in a magnetic Co-rich core of the grain with non-magnetic or weakly magnetic Cr-rich grain boundaries [6,7], as shown schematically in Fig. 1b. Thus, by tuning to the Cr edge, we enhance the chemical contrast between the magnetic grain core and the Cr-rich grain boundaries.

The Co-edge scattering is expected to arise from both magnetic and chemical correlations (and their interference). These data show the same interference peak at $q \cong 0.07$Å^{-1} that was observed in the

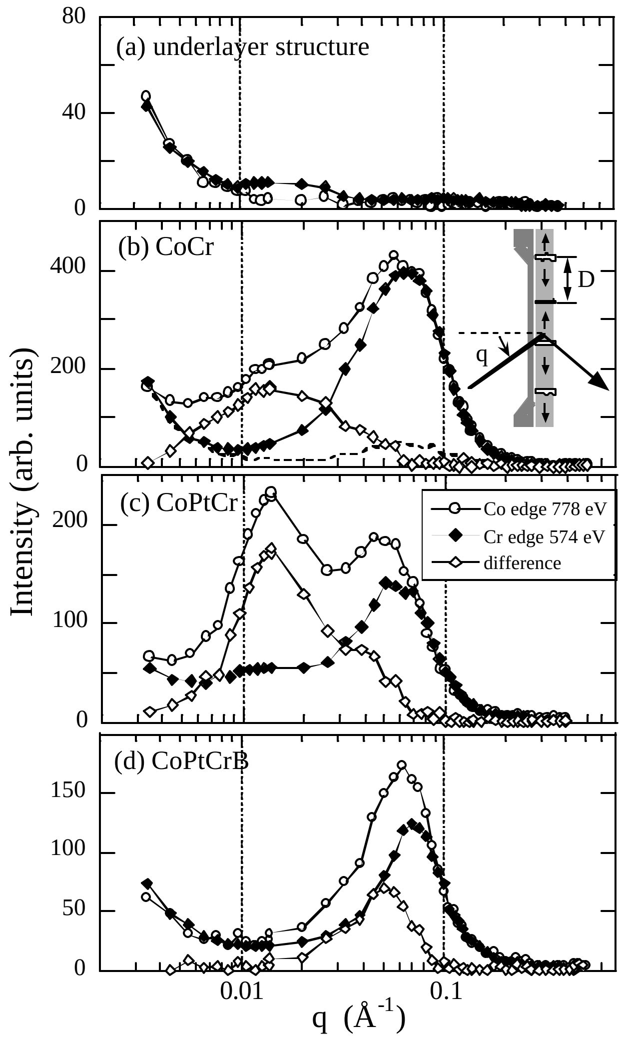

Figure 1. Resonant SAS from the underlayer structure without media layer (a) and from CoCr (b), CoPtCr(c), and CoPtCrB (d) media measured at the Co and Cr L3 lines as indicated. The inset shows the scattering geometry and media layer with magnetic grains (diameter D) with the in-plane magnetization direction represented by the arrows and nonmagnetic grain boundaries. The open diamonds are the difference between the Co- and Cr-edge data. The dashed line in (b) is the nonresonant scattering measured 10 eV below the Co edge.

Cr-edge data, as well as additional scattering at significantly lower q values. The observation of high-q resonant scattering from the grain structure at both the Co and Cr edges confirms that this scattering arises from in-plane compositional variations of Co and Cr. The additional lower-q scattering arises predominantly from correlated magnetic regions larger than the grain size. For the CoPtCr film (Fig. 1c), this additional scattering is clearly resolved as a peak at $q \cong 0.015$ Å^{-1} corresponding to a real space distance of $\cong$ 400 Å. The difference of the Co and Cr resonant scans (scaled to match at high q) results from Co magnetic-magnetic correlations and magnetic-charge interference, with the former dominating the low-q peak and the latter contributing progressively to increasing q. The low-q peak is thus a measure of the magnetic correlation length in these media films.

Boron additions are seen to reduce the magnetic correlation length from 4-5 times the chemical grain size to closely approach the grain size, consistent with improved recording performance and inferred magnetic correlation lengths from recording signal to noise measurements.

MODELING ENERGY SPECTRA

The above interpretation of magnetic and chemical peaks is qualitative. One approach to independent, quantitative determination of the scattering sources contributing to the peaks is to model the energy spectra of the scattering at each peak [5]. Measured Co L_3 energy spectra at these two peaks for the CoPtCr sample are shown as symbols in Fig. 2, and clearly have very different shape. Modeling these resonant shapes requires measured values of charge and magnetic atomic scattering factors f for Co. These were obtained from transmission absorption measurements of the saturated media film with linear and circular polarization, followed by Kramers-Kronig transformation of the imaginary part of these quantities to obtain their real parts. Non-resonant f values for Cr and Pt were taken from tabulated values [9].

Following standard SAS formalisms, the amplitude for different scattering sources is given by the difference of amplitudes of the two phases defining the heterogeneity. The simplest model for pure magnetic scattering yields amplitude proportional to the magnetic part of f for Co [5, 6]. The corresponding intensity is scaled and plotted in Fig. 2, with a small non-resonant background added.

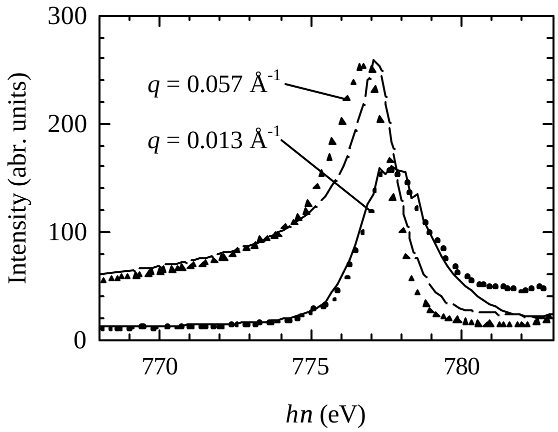

Figure 2. SAS energy spectra across the Co L_3 line of the CoPtCr media at the high- and low-q peaks (symbols). Model spectra based on measured Co resonant scattering factors (lines) confirm the magnetic and chemical origin of the two peaks.

The good agreement of model and measured spectra confirms the magnetic origin of the low-q peak and thus that magnetic correlation lengths in this sample are several times the chemical grain size. Modeling the high-q spectrum requires postulating compositions of the segregated phases at the grain boundaries and centers, forming the appropriate scattering amplitudes of these two phases as linear combinations of elemental scattering factors, and squaring the difference of these amplitudes to obtain the intensity spectrum. A model spectrum is scaled and plotted with the high-q data in Fig. 2, confirming that the high-q peak is consistently modeled assuming chemical origin. Details showing that this model is sensitive to the composition of segregated phases are in ref. [5].

CONCLUSIONS

Resonant SAS contrast at Co and Cr $L_{2,3}$ lines strongly enhances both magnetic and chemical scattering in recording media films. Since Co and Cr enhancements have different sensitivity to chemical and magnetic heterogeneity, their relative behavior allows clear separation of chemical and magnetic length scales and a very direct measurement of magnetic correlation lengths in granular recording media. The addition of B to the media alloys significantly reduces the magnetic correlation lengths [4]. Modeling of resonant energy spectra at the Co L_3 edge using measured resonant Co scattering factors quantitatively confirms magnetic and chemical scattering sources and provides an estimate of the composition of segregated phases yielding the chemical scattering [5].

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This work and JBK were supported by the Director, Office of Energy Research, Office of Basic Energy Sciences, Materials Science Division, of the U.S. Department of Energy under Contract No. DE-AC03-76SF00098.

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